Global Precipitation Measurement (GPM) Project

Three-Axis Magnetometer Performance Specification

Goddard Space Flight Center
Greenbelt, Maryland

National Aeronautics and
Space Administration

CM FOREWORD

This document is Global Precipitation Measurement (GPM) Configuration Management (CM)-controlled document. Changes to this document require prior approval of the applicable Configuration Control Board (CCB) Chairperson or designee. Proposed changes shall be submitted to the GPM CM Office (CMO), along with supportive material justifying the proposed change. Changes to this document will be made by complete revision.

Questions or comments concerning this document should be addressed to:

GPM Configuration Management Office

Mail Stop 422

Goddard Space Flight Center

Greenbelt, Maryland 20771

CHANGE RECORD PAGE

Version	CCR #	CCR Date	MOD #	MOD DATE	Description	Section Affected
Rev -	096	01/30/09			Baseline	All

TABLE OF CONTENTS

Page

LIST OF FIGURES

Figure Page

LIST OF TABLES

Table Page

1 SCOPE

This specification describes the electrical, mechanical, operating environment, and verification testing requirements for a space-qualified Three-Axis Magnetometers (TAM) for a Goddard Space Flight Center (GSFC) payload, the Global Precipitation Measurement (GPM) Mission.

2 DOCUMENTS AND DEFINITIONS

2.1 APPLICABLE DOCUMENTS

The following documents and drawings shall apply to the fabrication and to the electrical, mechanical, and environmental requirements of the TAM to the extent specified herein. In the event of conflict between this specification and any referenced document, this specification will govern, with the exception of the Statement of Work, GPM-GN&C-SOW-0010, in which case the SOW takes precedence.

The following is a list of the applicable specifications and publications.

Table 2-1 List of Documents

DOCUMENT NUMBER	TITLE
GPM-GN&C-SOW-0010	GPM Three-Axis Magnetometer Statement of Work
GPM-GN&C-DILS-0005	GPM Three-Axis Deliverable Items List and Schedule
422-40-01-004	**GPM Mission Assurance Requirements**
422-40-03-001	**GPM Core Spacecraft Performance Requirements**
GPM-ESE-REQ-006	CORE Observatory Electrical Systems Requirements
JSC-SN-C-005	Contamination Control Requirements for the Space Shuttle Program

2.2 DEFINITIONS

2.2.1 Flight Unit

A Flight Unit is hardware that will be used operationally in space. A Protoflight Unit, described below, is considered a Flight Unit.

2.2.2 Protoflight Unit

A Protoflight Unit is Flight hardware of a new design. It is subject to a test program that combines elements of prototype and flight acceptance verification; that is, the application of design qualification test levels and flight acceptance test durations.

3 REQUIREMENTS

In this document, a requirement is identified by “shall”, a good practice by “should”, permission by “may”, or “can”, expectation by “will” and descriptive material by “is”. All of the written requirements in this document must apply at the end of spacecraft (SC) life (EOL), as defined in Section 3.5.

3.1 DESCRIPTION

MAG-32 The TAM shall provide magnetic field measurements of the Earth’s magnetic field to determine the orientation of the spacecraft in inertial space as a key part of the GPM attitude control system. The TAM is defined as one combined sensor and electronics unit.

3.2 COMPONENT-SPECIFIC FUNCTIONAL/PERFORMANCE REQUIREMENTS

MAG-34 The TAM shall operate and perform within the following limits.

3.2.1 Lifetime

MAG-36 The TAM shall operate within specification during the component mission life as defined in Section 3.5.1.

3.2.2 Range

MAG-38 The full-scale output voltage for each axis shall be +10 VDC for the full-scale range of +1000 milligauss and -10VDC for the full scale range of -1000 milligauss.

3.2.3 Accuracy

MAG-40 The TAM output shall have an accuracy of less than or equal to 2% of full scale.

3.2.4 Scale Factor

MAG-42 The signal outputs shall respond to changes in the magnetic field intensity at a sensitivity of 10.0 mV/mG.

3.2.5 Null

MAG-44 The signal outputs in the absence of a magnetic field shall be within 0 volts ± 40 millivolts.

3.2.6 Linearity

MAG-46 The TAM signal outputs shall be linear to within ±0.2 percent of full scale over the range established in Section 3.2.2.

3.2.7 Saturation Level

MAG-48 Saturation level shall not be affected when the TAM is subjected to magnetic field intensities greater than twice the full-scale range in either direction.

3.2.8 Phasing

MAG-50 Positive output voltages shall represent positive field direction and negative output voltages shall represent negative field direction, as referenced to the axes directions shown in Figure 3-1 below.

3.2.9 Output Ripple

MAG-52 The output ripple voltage of the TAM signal outputs shall not exceed 10 mV rms.

3.2.10 Noise

MAG-54 The peak-to-peak noise in the frequency range of 0 to 100 Hz shall not exceed 7 mV.

3.2.11 Crosstalk and Misalignment Sensitivity

MAG-56 The TAM output signal voltages of 2 axes, with the third axis sensor exposed to a magnetic field of full-scale level as established in Section 3.2.2 along its sensitive axis, shall not exceed the equivalent of 0.25 degrees from the sensor reference surfaces.

3.2.12 Temperature Stability

MAG-58 The TAM signal outputs at null shall not change by more than 10 mV DC over the operational temperature ranges given in Section 3.6.5.

3.3 PHYSICAL CHARACTERISTICS

3.3.1 Design for Demise

MAG-61 In order to limit debris re-entry survival, each TAM component shall satisfy the following two conditions:

(1) melting point below 1000°C, or all linear dimensions below 0.20 m

(2) mass below: 3.0 kg of stainless steel alloys, or 1.0 kg of titanium alloys, or 1.0 kg of beryllium alloys, or 10.0 kg of aluminum alloys, or 1.0 kg of any material with a melting point greater than 1000°C. All parts exceeding the required thresholds shall be identified.

3.3.2 Mass

MAG-63 Total as delivered TAM mass shall be less than or equal to 600 grams (g).

3.3.3 Center of Mass

MAG-65 The contractor shall define the center of mass. The center of mass shall be determined to within ±6.5 mm relative to an external reference.

3.3.4 Envelope

MAG-67 The TAM, including connectors, shall occupy a space of less than:

length: 16.5 cm; (6.5 in.)

width: 8.5 cm; (3.3 in.)

height: 5.1 cm; (2.0 in.)

For the purposes of clarifying this requirement, the X-Y plane defines the mounting surface and the Y-Z plane defines the connector face. See figure below:

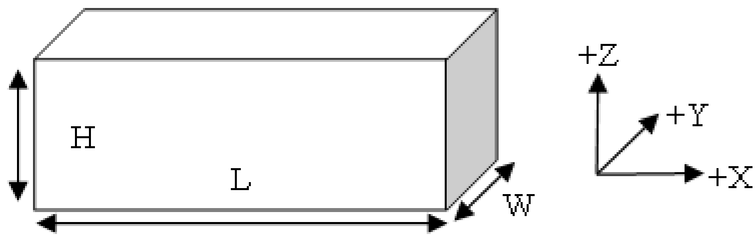


Figure 3-1 Envelope Dimension Definitions

3.3.5 Minimum Resonant Frequency

MAG-83 The TAM shall have a fundamental frequency greater than 100 Hertz (Hz) when hard mounted at the spacecraft interface. Flexures are considered as part of the component. This requirement shall be verified by test during structural sine sweep testing.

3.3.6 Mounting

MAG-85 The package will be hard-mounted on a mechanical surface of the spacecraft structure. Proper fit/alignment of the TAM to the structure shall be inherent in its design, fabrication, and assembly to the structure, through the use of close dimensional control in the location of mounting holes and the use of correct mounting hardware. The mounting interface shall be defined in the Interface Control Document (ICD).

3.3.7 Alignment

MAG-87 The TAM sensor axis designated as the z axis shall be normal to the mounting surface. The sensor axes shall be marked on the unit housing in agreement with Figure 3-1. All axes shall be aligned and orthogonal within the tolerance listed below.

Axes Alignment	<3.0 degrees
Axes Orthogonality	<3.0 degrees
Axes Knowledge	<1.0 degrees

3.3.8 External Adjustment

MAG-91 The TAM shall be designed so that no external adjustments are required after start of acceptance or qualification testing.

3.3.9 Finish

MAG-93 All parts should be passivated and external mounting surfaces shall be conductive as defined in Section 3.4.18.1. (Surface Conductivity). Aluminum parts shall be finished with iridite per MIL-DTL-5541F, Class 3. Titanium parts shall be finished per SAE AMS 2488D.

3.3.10 Identification and Marking

MAG-95 Each unit shall be permanently marked with the part number and a unique sequential serial number in the area designated on the Interface Control Drawing in a manner to be approved by the GSFC Contracting Officer's Technical Representative (COTR).

3.3.11 Fastener Locking

MAG-676 All threaded fasteners used in GNCS hardware components shall employ a locking feature.

3.4 ELECTRICAL CHARACTERISTICS

MAG-97 The electrical interface configuration shall meet the overall requirements of this specification.

3.4.1 Power Input Configuration

MAG-99 Power to the TAM will be remotely switched using properly derated lines. The dc power and return will be routed to the TAM as twisted pairs and will be shielded as required. The power inputs and their associated returns shall not use adjacent pins on the connector.

3.4.2 Power Consumption

MAG-101 The maximum power required by the TAM when providing full output in all 3 channels simultaneously shall not exceed 2.0 W.

3.4.3 Input Voltage Level

A regulated voltage source of ±15 V DC (regulated to within 10% of nominal value) will be supplied.

3.4.4 Input Noise and Ripple

MAG-105 The TAM shall meet its performance requirements in the presence of a 50 mV peak-to-peak ripple over the frequency range of 1 Hz to 10 MHz at the Power input.

3.4.5 Turn-On Transients (In-Rush Current)

MAG-107 Turn-on transient current drawn by the TAM shall not exceed 10% of the maximum steady-state current.

3.4.6 Operational Transients

MAG-116 Operational transients shall not exceed 125 percent of the maximum current drawn during peak power operation (25 percent higher than peak operational current) with the maximum duration not to exceed 50 ms and the rate of change of current during the transients not to exceed 5 mA/µs.

3.4.7 Turn-Off Transients

MAG-118 For +15 Vdc: When the service is switched off, the peak voltage transient induced on the power service shall not exceed +16 Vdc nor drop below -0.5 Vdc with respect to ground.

MAG-673 For -15 Vdc: When the service is switched off, the peak voltage transient induced on the power service shall not exceed -16 Vdc nor drop below +0.5 Vdc with respect to ground.

Note: The power supply return (-) must be grounded to the chassis of the box and this test is not to be verified with Flight components.

3.4.8 Turn-Off Protection

MAG-120 The TAM shall not be damaged by the unannounced removal of power.

3.4.9 Internal Fusing/Over-Current Protection

MAG-122 The TAM shall not use non-resetting over-current protection (i.e., fuses) internal to the TAM.

3.4.10 Test Inputs

MAG-124 There shall be a capability to simulate the Earth's magnetic field for ground testing purposes.

MAG-125 Component test interfaces shall follow the test signal rules below.

The component may include test signals at test connectors that are not directly wired to a flight circuit (not isolated) and that are used for ground test operations.

MAG-127 Test connectors shall meet the same specifications as any flight connector on the component.

MAG-128 The Contractor shall provide flight-approved RF, static control covers, connector savers, and mating connectors for all connectors.

MAG-129 Circuits wired to the test connectors shall be designed to prevent damage due to an external short, test equipment malfunction, or ESD.

MAG-130 Component power shall not be applied or accessed at or through a test connector

3.4.11 MACE Interface

The TAM shall provide the following outputs to the Mechanism Attitude and Control Electronics (MACE).

X Component of Magnetic Field	Active Analog
Y Component of Magnetic Field	Active Analog
Z Component of Magnetic Field	Active Analog
Sensor Thermistor	Passive Analog
Electronics Thermistor	Passive Analog

3.4.12 Other Telemetry

MAG-132 The TAM shall provide separate temperature measurements of the sensor and electronics using a thermistor device.

3.4.13 Connectors

MAG-134 External box connectors shall be chosen from those in the EEE-INST-0002. If the component requirements cannot be met using one of these connectors, equivalent alternates may be used if it meets the derating criteria of EEE-INST-0002, or after successful completion of a qualification program based upon the guidelines contained therein.

3.4.14 Wiring

MAG-136 Conventional wire used in the spacecraft harness or any of the subsystem harnesses shall conform to the following requirements.

MAG-137 Minimum allowable wire size for power shall be 22 AWG. Minimum wire size for signals shall be 24 AWG.

MAG-138 All harnessing shall be fabricated from low outgassing material that is non-flammable or self-extinguishing. (per EEE-INST-002)

MAG-139 All current carrying power wires shall be derated in accordance with GSFC EEE-INST-0002

MAG-140 Wire shields shall not be used for power or power return.

3.4.15 Wire Sizing and Number

MAG-142 The TAM shall provide two power and two return inputs, each sized appropriately, to accommodate the peak operating current draw from the power system and remain within derating guidelines of EEE-INST-0002 for wire in a bundle. This requirement must still remain after one wire is in an open circuit condition.

3.4.16 Cable and Signal Shielding

MAG-144 All signal lines shall be shielded. Power wires shall be shielded on a case by case basis, if it is determined to be necessary by the EMC tests performed before TAM delivery. All shields shall be grounded to the chassis of the TAM and not brought through the connectors unless approved by the COTR.

3.4.17 Grounding

MAG-146 The DC electrical resistance across the TAM to mounting interfaces shall not exceed 2.5 mΩ. (Assume bolted to aluminum interface with no interface material). Mating surfaces shall be free from nonconductive finishes and shall maximize contact surface area. Connector shells shall be electrically bonded to the chassis through an electrical resistance not exceeding 5 mΩ. Unless specifically approved by the GSFC COTR, the component's ground connection shall be made through its mounting interface.

MAG-693 The TAM shall isolate the +/- 15 Vdc power, the +/-15V power return, and all signal grounds from the component chassis by at least 1 Megaohm.

MAG-694 The TAM shall provide a threaded hole to accommodate a ground lug for traveling grounds during handling and transportation.

3.4.18 Bonding or Mating

MAG-148 The primary mating method for the TAM shall be the metal-to-metal contact between component mounting feet (or baseplate) and the GPM structure. Mating (electrically bonding) surfaces should be free from nonconductive finishes and should establish sufficient conductive contact surface area such that the electrical direct current (DC) resistance between the mating surface of the TAM and the mating structure shall not exceed 5 milliohms DC.

MAG-149 If the TAM is to be mounted on a composite or other low conductive material, a grounding strap shall be attached from the component chassis to an Orbiter conductive structure.

3.4.19 Surface/Dielectric Charging Protection

MAG-151 The component shall meet the following requirements in order to survive the LEO charging environment.

3.4.19.1 Surface Conductivity/External Discharge Protection

MAG-153 External surfaces on externally mounted components shall be conductive with a resistivity of less than 1E9 ohms/sq. and grounded to the Observatory structure, so that charge can bleed from that surface faster than the charge can build up on that surface.

MAG-154 The component shall be designed to prevent discharges on the external surfaces from permanently damaging components or upsetting data collection.

MAG-155 The component's electrical system shall be designed to carry discharge currents and to shield from the electric field from the discharge without any permanent damage to the Observatory.

3.4.19.2 Internal Charging

MAG-157 The component design shall prevent internal charging/discharging effects that can damage the internal components or disrupt operations. Internal charging effects shall be controlled by shielding all electronics elements with sufficient aluminum equivalent thickness (110 mil Al for bulk dielectrics or to 60 mil Al equivalent for Teflon harness insulation) so that the internal charging rate is benign.

MAG-158 Internal dielectrics materials with bulk resistivity of >10E12 ohm-cm (such as the connectors, thermal isolators, thermistor mounting, and other materials such as Kapton and Teflon insulators) that do not meet the shielding requirement shall be controlled via one of the methods described in the following paragraphs below.

Limit the electron flux to insulators by shielding to 10E10 electrons/cm^2 in 10 hours. (This can be met with plate shielding with 110 mil Al for bulk dielectrics or to 60 mil Al equivalent for Teflon harness insulation.)

Filter nearby circuitry to withstand a 5,000-Volt, 20-pf, 10-ohm discharge. Detailed analysis of discharge could result in smaller or larger discharge source than above.

Coat the exterior surface of the dielectric with a grounded layer with a resistivity of <1E9 ohm/sq.

Prevent the discharge from reaching a victim circuit by EMI shielding and or grounded conductive barrier that will safely absorb and dissipate the discharge.

MAG-163 If none of above control techniques can be applied, the impacts of the discharge from the dielectric material shall be assessed for an approval.

MAG-164 Ungrounded (floating) conductors shall not be allowed in the component. This includes unused wires in harnesses; ground test sensors; unused or unpopulated circuit board traces; ungrounded IC, relay, transistor, or capacitor cases; spare pins in connectors; aluminum or copper tape; ungrounded bracketry for harness or connectors; TC105 harness tie-down clips; harness P-clamps; conductive epoxy; thermostat cases; screws; or nut plates.

MAG-165 Leakage impedance of conductive internal parts shall be less than 10,000 ohms. This requirement applies to conductive fittings on dielectric structural parts. Further investigation into these effects and mitigations of internal charging can be found in the NASA document, Avoiding Problems Caused by Spacecraft On-Orbit Internal Charging Effects, NASA-HDBK-4002.

3.4.20 Dielectric Strength

MAG-167 Dielectric material between mutually isolated electrical circuits shall withstand a test voltage of at least 100 VAC for 60 seconds without exceeding a current of 1.0 mA.

3.4.21 Insulation Resistance

MAG-169 Insulation resistance between mutually isolated electrical circuits shall be at least 100 megaohms at a test voltage of at least 50 Vdc for 60 seconds minimum.

3.4.22 Deleted

3.4.23 EEE Parts Program

MAG-678 A EEE parts program shall be planned for and implemented for the flight GNCS flight hardware for the purpose of part selection, de-rating, screening, and overall qualifications.

3.5 LIFE REQUIREMENTS

3.5.1 Mission Life

MAG-174 Component orbit life shall be 5 years as defined herein.

3.5.2 Shelf Life

MAG-176 The component shall not suffer any degradation in performance when stored for ten years when packaged using agreed-to procedures.

3.6 ENVIRONMENTAL REQUIREMENTS

MAG-178 The component shall be designed to withstand (without degradation of specified performance) the operational and non-operational environments specified in the following section.

3.6.1 Static Loads

MAG-180 Static design loads shall be taken from the mass acceleration curve below. The component shall demonstrate its ability to meet its performance requirements after being subjected to the appropriate net center of gravity (CG) limit load. These design loads are intended to cover low-frequency dynamic inputs less than 100Hz, as well as static inputs on components and subsystems typically less than 100 kg. Loads are to be applied independently in each axis. High-frequency dynamic inputs up to 2000Hz shall be addressed using random vibration loads. For components with a mass less than 0.5 kg the static design load is 36 g.

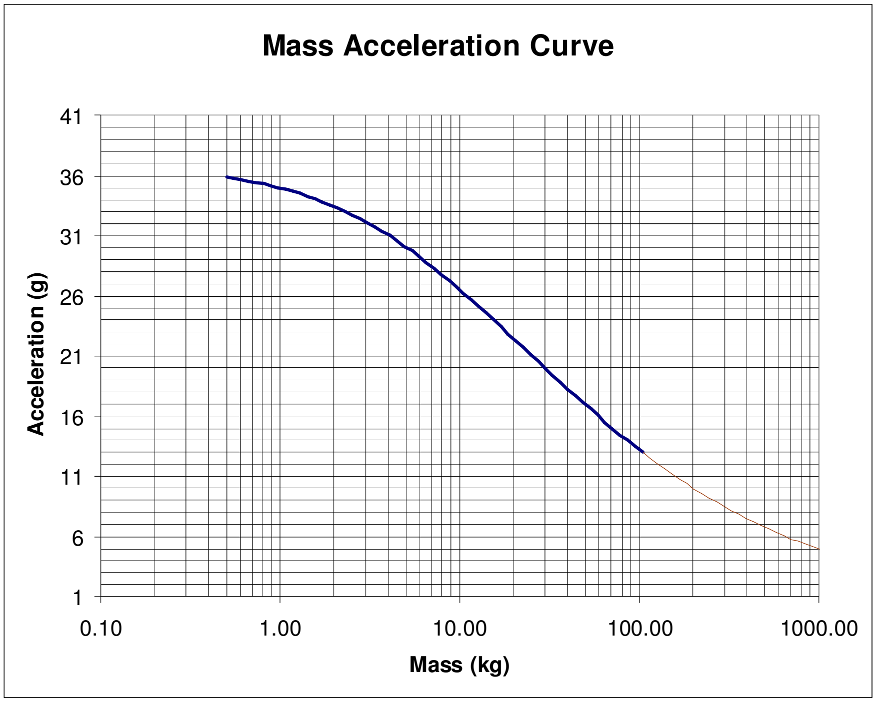


Figure 3-2 Mass Acceleration Curve for Static Load Limits

3.6.2 Vibroacoustic Loads

MAG-184 The TAM shall be capable of withstanding the random vibration levels shown in Table 3-1 and the sine vibration levels of Table 3-2, individually applied to three mutually orthogonal axes.

Table 3-1 Random Vibration

FREQUENCY (HZ)	Acceptance (Flight) LEVELS (g2/Hz)	Qualification (PROTOFLIGHT and PROTOTYPE) LEVELS (g2/Hz)
20	0.013	0.026
20-50	+6 dB/oct	+6 dB/oct
50-800	0.080	0.160
800-2000	-6 dB/oct	-6 dB/oct
2000	0.013	0.026
Overall Grms	10.0 Grms	14.1 Grms

MAG-215 The above random environment is appropriate for components weighing 22.7 kilograms (kg) (50 pounds [lbs]) or less. This environment will be updated with random vibration analysis. Note for lightweight components, the highest design loads may be from this random vibration environment. The contractor shall perform random vibration analysis along with static loads analysis. Please see NASA-HDBK-7005 and NASA-STD-7001 for more information.

Table 3-2 Sine Vibration Test Levels

	Acceptance		Qualification/Protoflight	
Axis	**Frequency (Hz)**	**Level (g)**	**Frequency (Hz)**	**Level (g)**
Axial	5-50	6.4	5-50	8.0
Lateral	5-50	6.4	5-50	8.0

MAG-240 Sine vibration levels may be notched to not exceed 1.25 times the design limit load taken from the curve in Section 3.6.1. These levels will be updated as coupled-loads analysis (CLA) data becomes available. The TAM shall test for this environment up to 50 Hz and analyze from 50 to 100 Hz.

3.6.3 Shock

MAG-242 The maximum expected shock environment at the component interface is shown in the figure below. The component shall be assessed for damage due to shock based on shock sensitivity or proximity to shock sources. If the component is not considered susceptible to the shock environment, shock testing can be deferred to the level of assembly that allows for actuation of the actual shock-producing device.

If the component is considered to be susceptible to the shock environment, the contractor may need to perform a shock test to demonstrate that the item can survive the predicted shock environment. The GPM Project will assess the final shock environment based on specific component location.

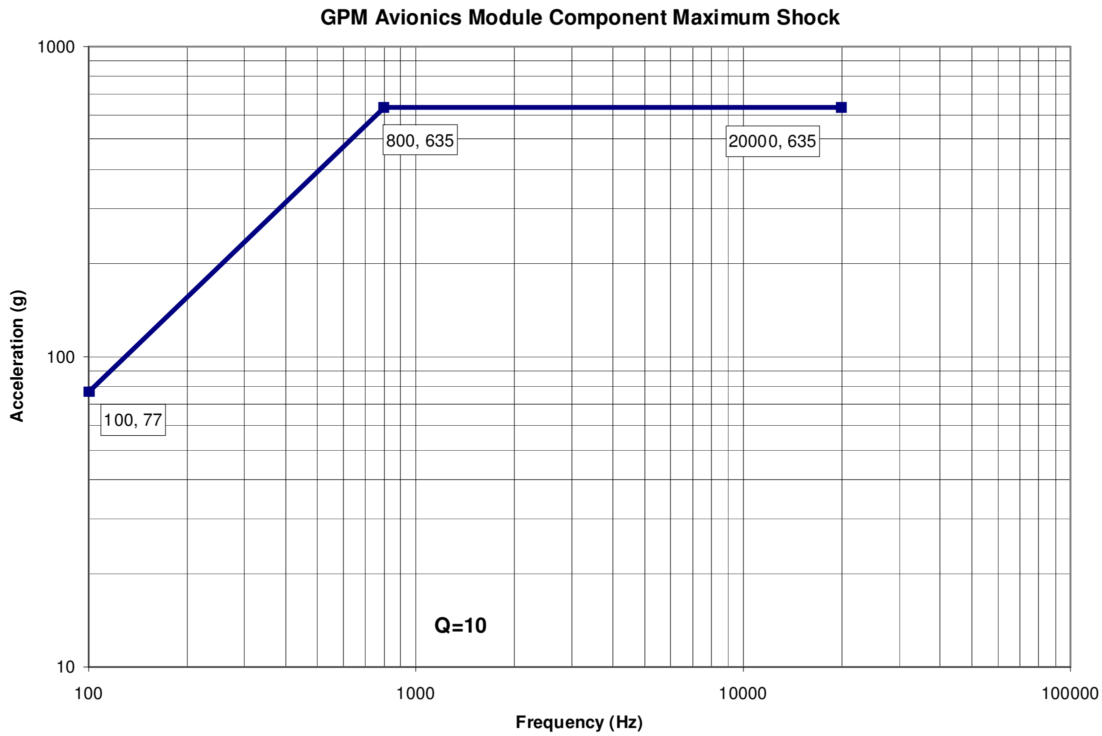


Figure 3-3 Component Shock Specification

3.6.4 Acoustic

MAG-247 The TAM shall be designed to meet its performance requirements after being subjected to the acoustic environment listed in the table below. The sound pressure levels are based on the specified launch vehicle only.

Table 3-3 Acoustic Levels for HIIA-202

Full Octave Frequency Band (Hz)	Flight/Acceptance Sound Pressure Level (dB)	Protoflight/Qual Sound Pressure Level (dB)
31.5	125	128
63	126.5	129.5
125	131	134
250	133	136
500	128.5	131.5
1000	125	128
2000	120	123
4000	115	118
8000	113	116
OSPL	**137.5**	**140.5**

3.6.5 Thermal

MAG-295 The TAM shall be capable of operation with interface temperatures defined in the table below. Unless specifically approved by the COTR, the thermal design shall dissipate heat conductively through the mounting interface, which should be assumed to be at the temperature appropriate to the different tests as shown in Table 3-4.

Table 3-4 Temperature Limits at Mounting Interface

Condition	**Cold Limit (degrees C)**	**Hot Limit (degrees C)**
Operational Temp (nominal expected orbital range)	-15	+60
Acceptance Temp	-20	+65
Qualification Temp	-25	+70
Survival Temp (each unit must turn on at these extremes but does not have to meet performance requirements)	-40	+85

3.6.6 Vacuum

MAG-319 The TAM shall be capable of meeting all performance requirements of Section 4.3 at ambient as well as when exposed to a vacuum environment of 1 x 10-5 Torr, or less.

3.6.7 Atomic Oxygen

MAG-321 Materials used in the construction of the TAM assembly shall not generate contamination products resulting from the interaction with an atomic oxygen environment and such that the AO environment does not compromise the spacecraft and instrument performance. . The atomic oxygen (AO) fluence for GPM Core Observatory surfaces in the velocity vector as a monthly basis is depicted in the figure below. The total AO fluence for the mission lifetime of 3 years plus 2 months is 9.76x1021 atoms/cm2 with no design margin. A minimum design margin of 1.5x shall be applied to account for analysis uncertainties.

Applying the 1.5x design margin results in the total AO fluence of 1.464x1022 atoms/cm2 for the mission.

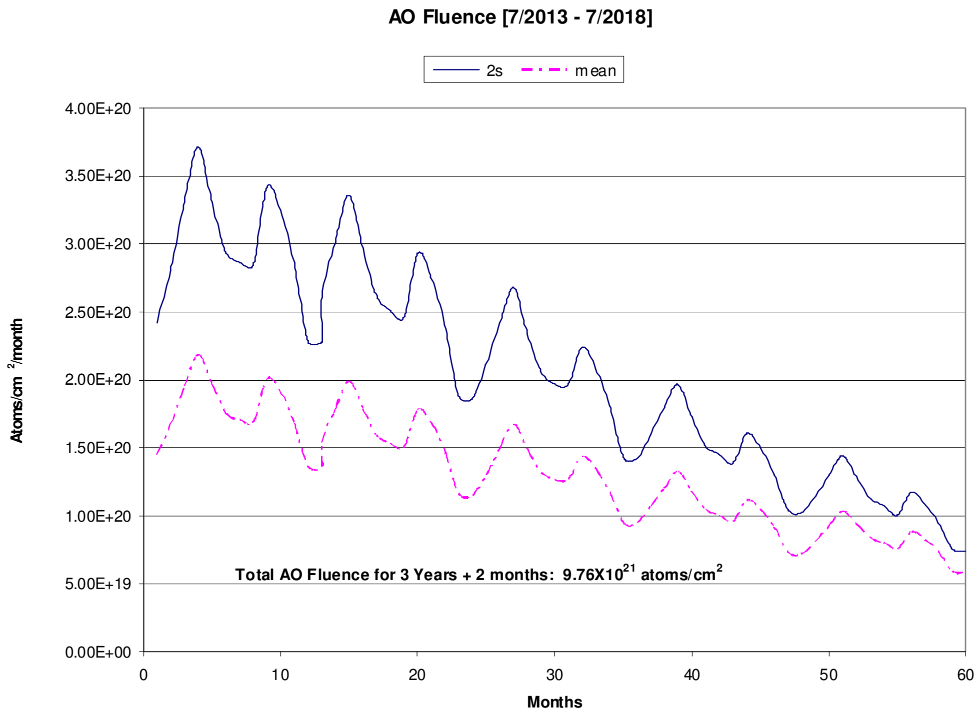


Figure 3-4 Atomic Oxygen Fluence For GPM Mission

3.6.8 Radiation

MAG-324 The TAM design shall protect against the radiation environment as shown in Figure 3-10 through Figure 3-16.

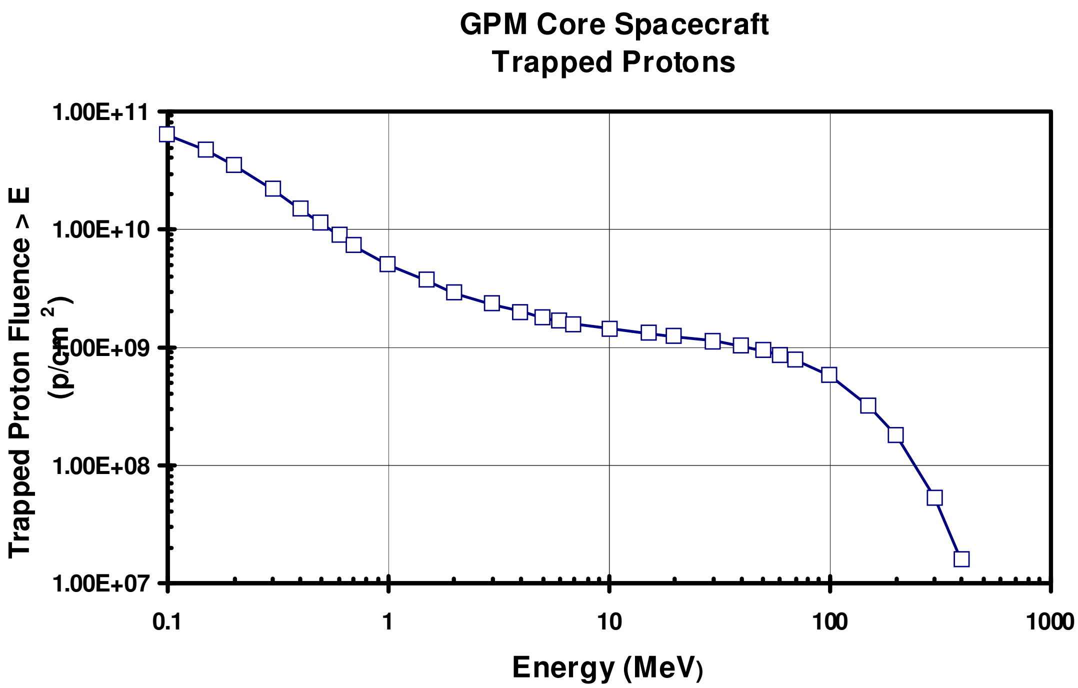


Figure 3-5 Surface Incident Integral Trapped Proton Fluence for 5-year Mission

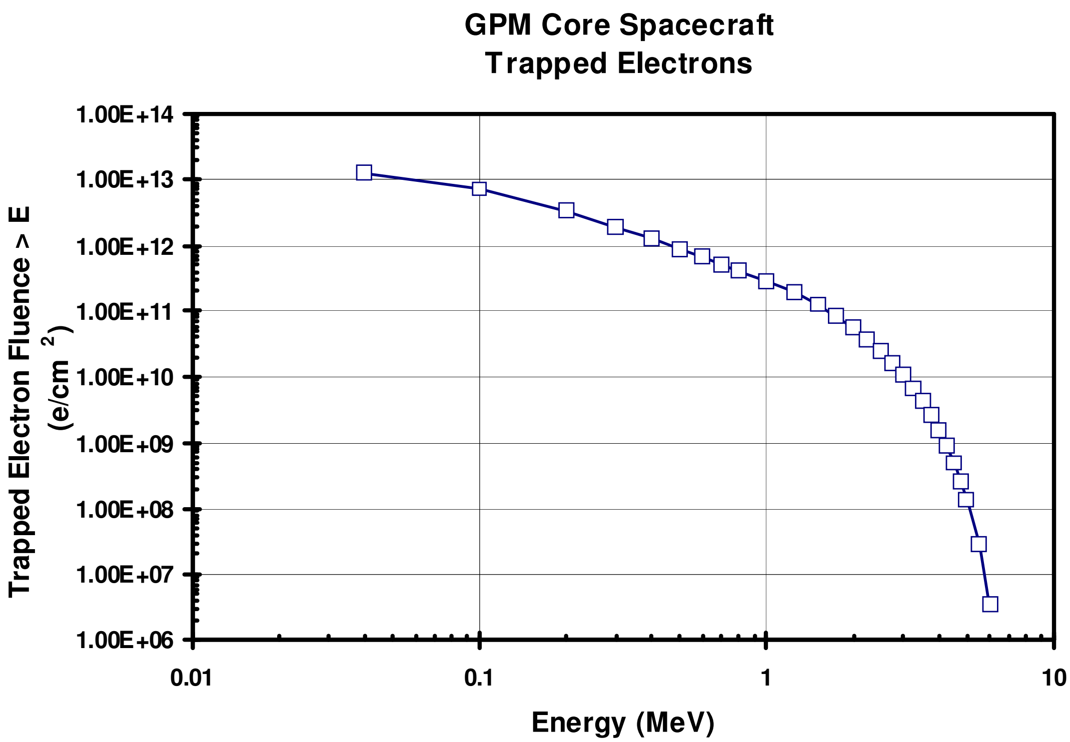


Figure 3-6 Surface Incident Integral Trapped Electron Fluence for 5-year Mission

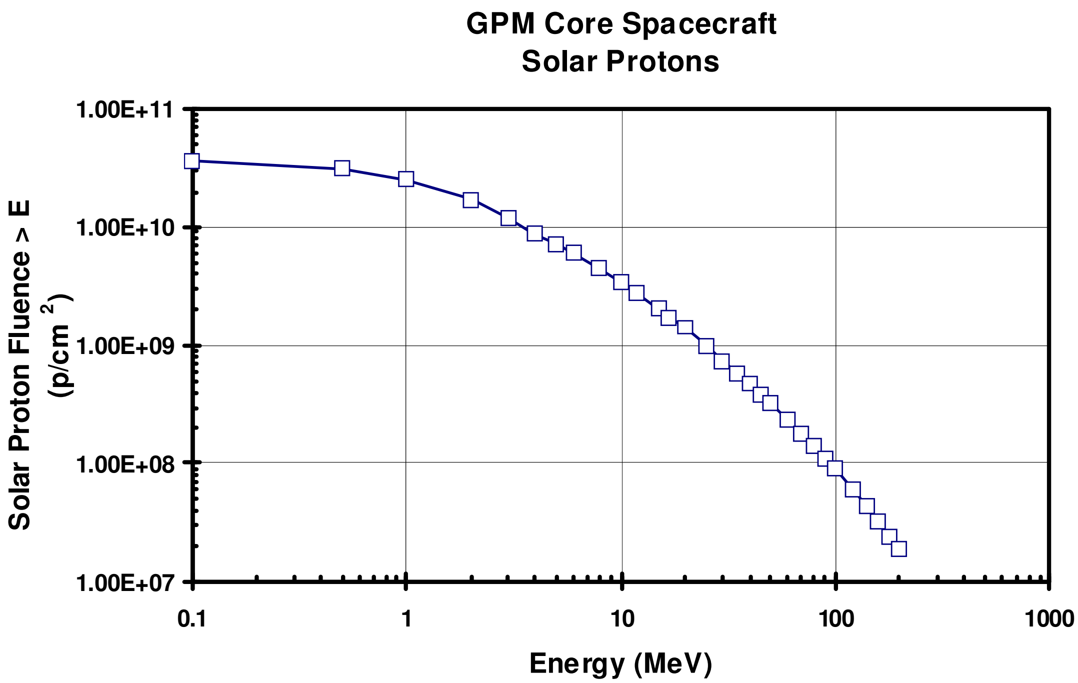


Figure 3-7 Surface Incident Integral Solar Proton Fluences for 5-year GPM Core Mission

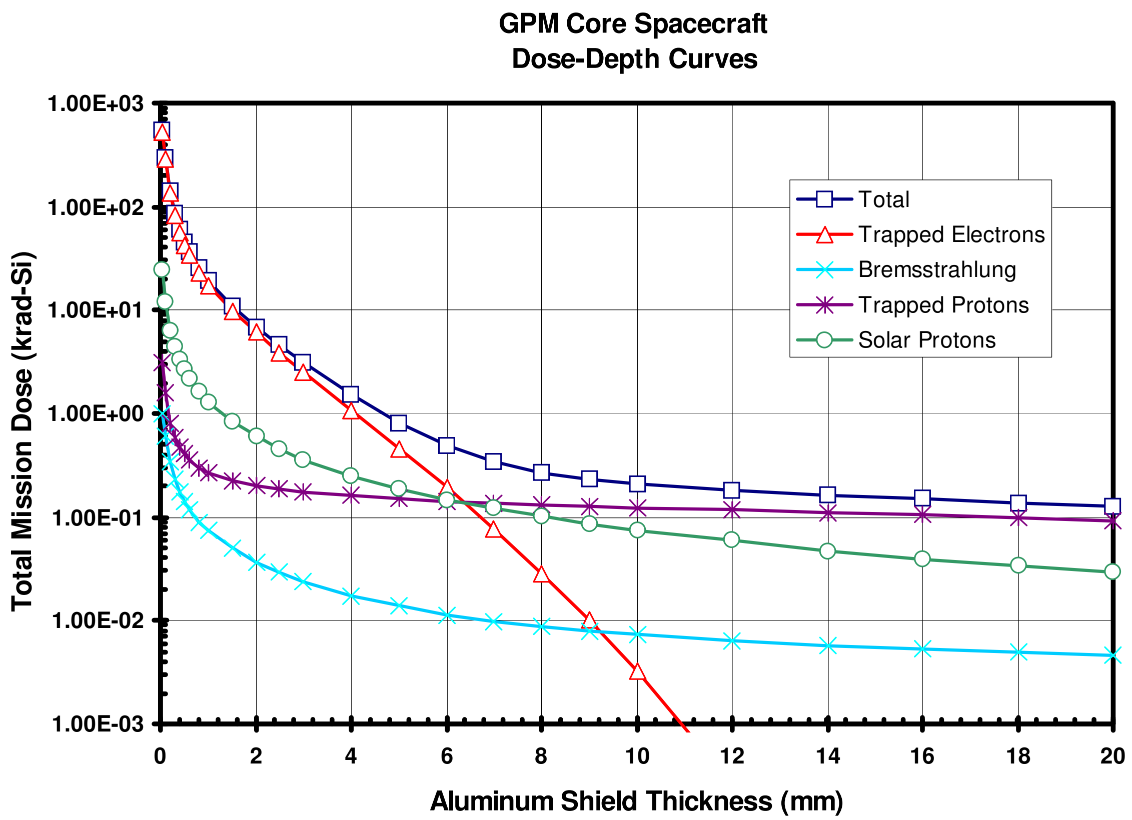


Figure 3-8 GPM Core mission total ionizing dose curves for dose at the center of solid aluminum spheres. Values do not include design margins.

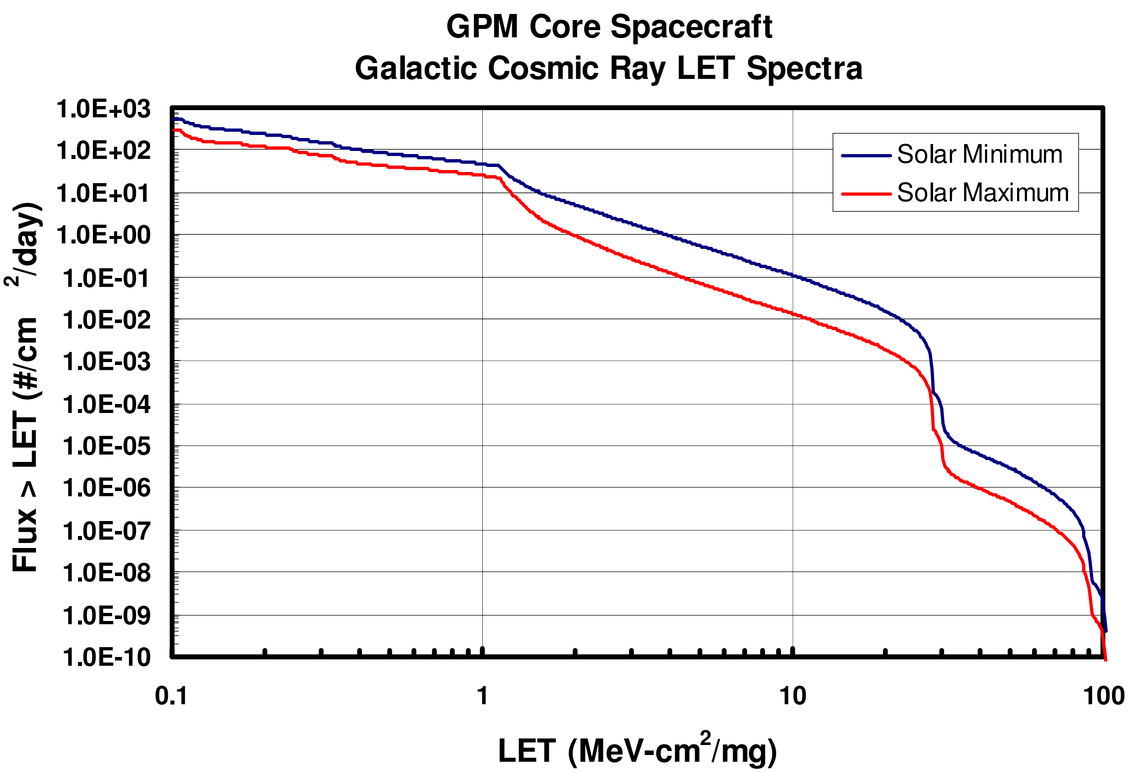


Figure 3-9 Integral LET spectra for galactic cosmic ray ions hydrogen through uranium assuming 100 mils of aluminum shielding

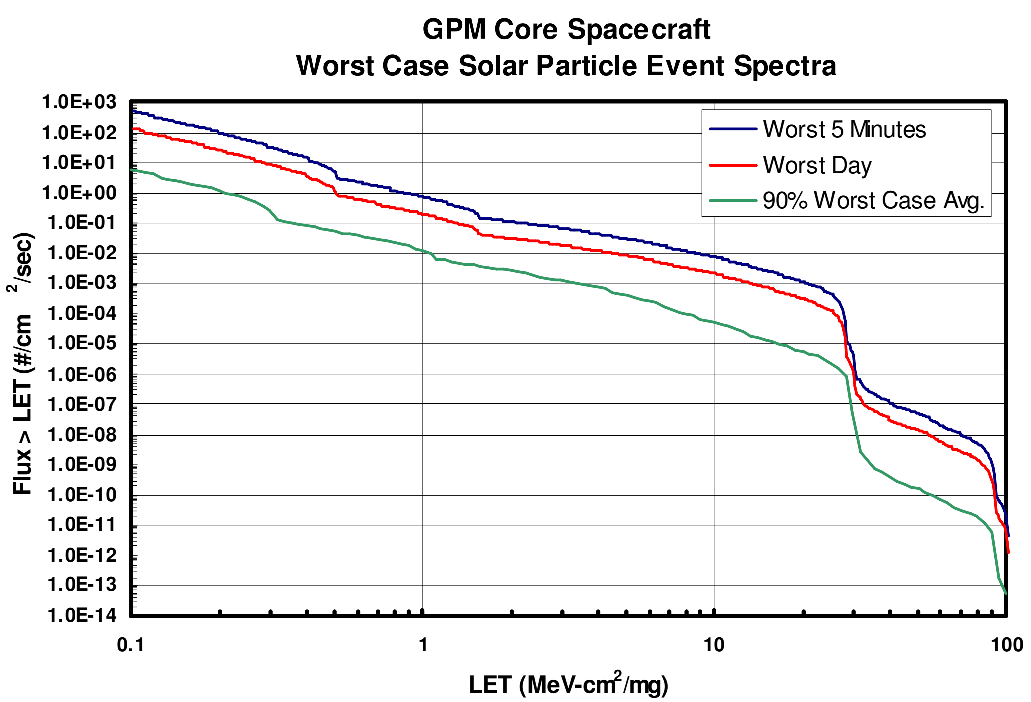


Figure 3-10 Integral LET spectra for hydrogen through uranium for 3 worst case situations:

(1) average over the peak 5 minutes of the October 1989 event,

(2) average over the worst day during the October 1989 event,

(3) 90% worst case average over the solar maximum period

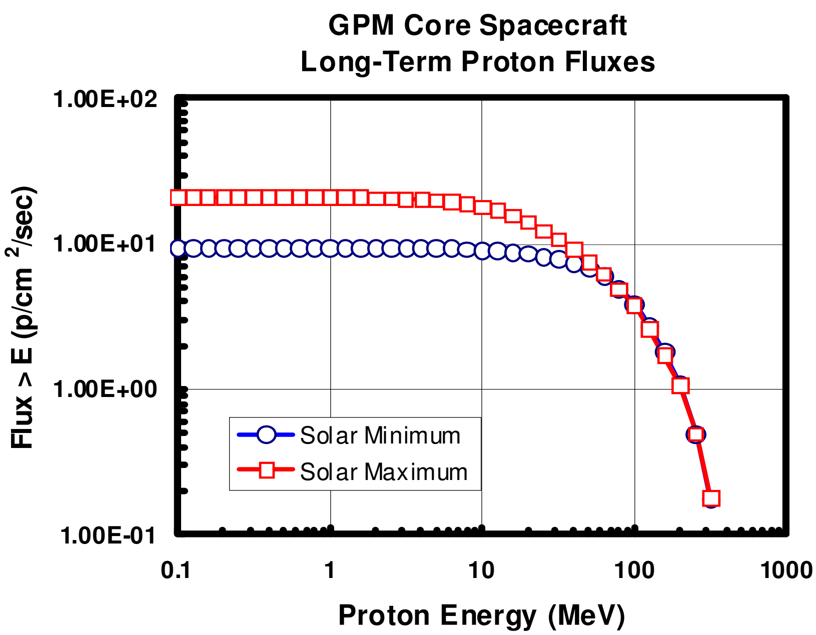


Figure 3-11 Long-term integral proton fluxes for single event effects evaluation.

Included are the trapped proton and solar proton fluxes behind 100 mils of aluminum shielding.

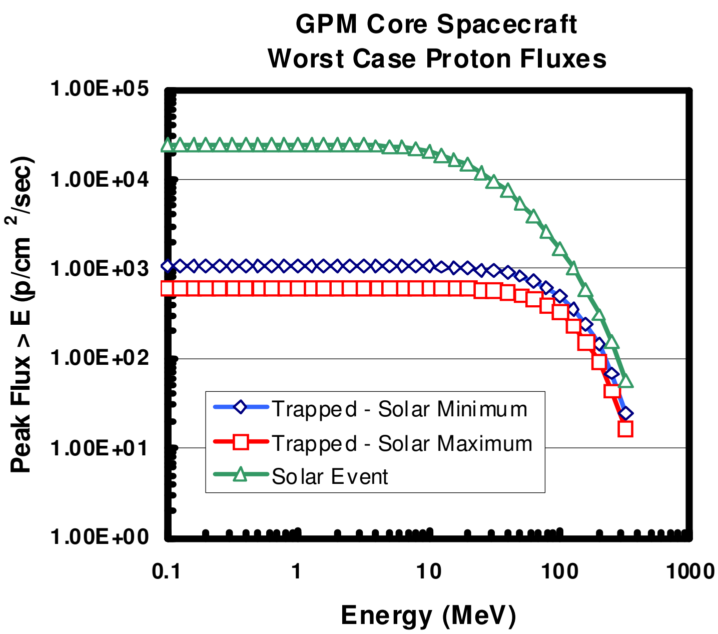


Figure 3-12 Worst case integral proton fluxes for single event effects evaluation. Included are the peak trapped proton fluxes averaged over a 1-minute interval during solar maximum and solar minimum. Also shown is the worst-case solar proton flux averaged over a 5-minute interval at the 90% confidence level. Calculations are done for 100 mils of aluminum shielding.

3.6.9 Radiation Survivability

MAG-351 No radiation-induced failure, anomaly or error shall result in the permanent loss of TAM capability for the mission duration and environments specified in Section 3.6.8.

3.6.10 Solar Event Survivability

MAG-353 The TAM shall be capable of surviving the worst-case solar particle event profiles (time, LET spectrum and particle fluxes and fluences) specified in Figure 3-10 through Figure 3-14.

3.6.11 Single-Point Failure Prevention

MAG-355 No radiation induced single part failure shall cause permanent loss of a function, or prevent access to extant redundant functionality.

3.6.12 Operability

MAG-357 The TAM shall operate through the worst-case flare environment as defined by Figure 3-14 and Figure 3-16.

3.6.13 Radiation Design and Verification Requirements

The following requirements delineate the analysis, test, and documentation requirements for the three major design areas of radiation environment mitigation; Single Event Effects (SEE), Total Ionizing Dose (TID), and Displacement Damage (DD).

3.6.13.1 Single Event Effects (SEE) Design and Verification Requirements

MAG-361 All SEE induced errors, failure modes and possible consequences (especially potentially destructive failures and operational anomalies) shall be documented.

3.6.13.1.1 *Destructive Single-Event Effects*

MAG-363 The TAM shall not use parts susceptible to destructive single-event effects. Any part with potential susceptibility to destructive SEE shall be characterized according to a test plan consistent with EIA/JESD57 "Test Procedures for the Measurement of Single Event Effects in Semiconductor Devices from Heavy Ion Irradiation" prior to its use. Any device that exhibits a high-current, nondestructive error mechanism giving rise to a current exceeding device specifications or a current density within the device greater than 106 A/cm^2 to 10^6 A/cm^2 shall be analyzed subsequent to SEE testing.

3.6.13.1.1.1 Single Event Latch-Up (SEL)

MAG-365 Parts susceptible to single-event latchup shall not be used without thorough characterization of all SEL modes to which the part is susceptible.

3.6.13.1.1.2 Single-Event Burnout (SEB) and Single-Event Gate Rupture (SEGR)

MAG-367 The TAM design team shall verify that all power MOSFETs, discrete bipolar junction transistors, FETs and other devices susceptible to SEB and/or SEGR are operating with all applied voltages in their safe operating regions (as determined by test or approved analysis).

3.6.13.1.1.3 Other Destructive Single-Event Modes

MAG-369 The TAM design team shall identify critical functions of all devices susceptible to single-event induced hard failure modes, as well as SEE modes that may result in latent damage, and supply sufficient information about these functions and their implementation to estimate failure rates. For the purposes of analysis, stuck bits shall be considered as destructive failures. However, annealing characteristics may be considered as mitigating factors in categorizing the resulting errors.

3.6.13.1.1.4 Mitigation of Destructive SEE

MAG-371 Where necessary and appropriate, the TAM design team shall implement and verify measures to mitigate unacceptable effects of SEE induced destructive failures. Any adverse consequences of the mitigation (i.e. diminished speed or performance, interruption of operations by spurious SEL indications, etc.) shall be documented.

3.6.13.1.2 *Nondestructive Single-Event Effects*

MAG-373 All non-destructive SEE modes shall be classified with respect to their duration, DT (time from incidence to full recovery of operations) and consequences (or criticality). The rates for non-destructive SEE shall not cause the TAM to violate the mission availability requirements.

3.6.13.1.3 *Propagation of Single-Event Effects*

MAG-375 No error caused by an SEE occurring in the TAM shall cause permanent loss of functionality to another subsystem outside of the TAM.

3.6.13.2 Total Ionizing Dose (TID) Design and Verification Requirements

MAG-377 The TAM design team shall perform an analysis documenting the effects of twice (2x) the expected mission total ionizing dose (TID) requirements. All TID effects shall be mitigated when they compromise mission objectives. The TID for GPM is 10.0 krads (Si) when behind 100 mils of aluminum equivalent shielding

3.6.13.3 Displacement Damage (DD) Design and Verification Requirements

MAG-379 The TAM design team shall demonstrate that the TAM performs its intended function with no system-level degradation after being exposed to a fluence of protons or neutrons causing an equivalent or greater amount of displacement damage than twice (2x) the mission dose predicted for the under worst case application conditions (including dose rate, applied voltages, temperatures, etc.). In the event that mitigation (shielding, etc.) of displacement damage effects is needed to ensure adequate performance, the effects of this mitigation on mission goals shall be analyzed prior to implementation. No mitigation of displacement effects shall be implemented that compromises the achievement of mission goals. If displacement damage mitigation is necessary, these measures and any potential effects on system performance and achievement of mission goals should be addressed in the displacement damage analysis report.

3.6.13.3.1 *Use of Non-Ionizing Energy Loss (NIEL) and Equivalent Fluence*

MAG-381 For the purposes of testing, Non-Ionizing Energy Loss (NIEL) may be used to determine an equivalent fluence of particles (protons or neutrons) at a single or a few energies to bound the mission fluence only if it is known that damage is proportional to NIEL for all particle energies. If application of NIEL leads to inconsistent equivalent fluences at different energies, then the fluence producing the highest displacement damage dose shall be used to bound the on-orbit degradation.

3.6.14 <u>Temperature Exposure Range</u>

MAG-683 The TAM shall be designed to withstand exposure to ambient temperatures between 5°C and 35°C without degradation to subsequent performance when unpowered.

3.6.15 Temperature Operations Range

MAG-684 The TAM shall be designed to operate within specification in an area where the ambient temperature is between 13C (55F) and 27C (80F) when powered.

3.6.16 Humidity

MAG-383 The TAM shall be capable of meeting the requirements herein during and after exposure to 30 to 70% relative humidity for 2 years.

3.6.17 Pressure Exposure Range

MAG-686 The GNCS flight hardware shall be designed to withstand exposure to ambient pressures of 300 millibars to 1300 millibars without degradation to subsequent performance.

3.6.18 Venting

MAG-385 All TAM shall be vented to prevent pressure buildup during the ascent phase of launch. The TAM shall survive external depressurization from one atmosphere (atm) to 10-5 Torr in 60 seconds.

MAG-386 GPM components not having a minimum of 0.25 square inches of vent area for each cubic foot volume, shall demonstrate the ability to survive the venting rate. If analysis is required, the venting analysis must indicate a positive structural margin at loads equal to the maximum expected pressure differential during launch, with a Factor of Safety of 2.0 applied to the loads.

3.6.19 Contamination Control

MAG-388 The contractor shall establish cleanliness requirements to minimize performance degradation and delineate the approaches to meet the GPM Project requirements.

3.6.20 Cleanliness

MAG-390 All hardware shall be fabricated in Class 300K or better cleanrooms per ISO 14644.

MAG-867 All hardware shall be verified to be visibly clean highly sensitive (per JSC-SN-C-005) with a blacklight inspection.

MAG-868 External cleanliness shall be verified prior to or upon delivery to Goddard. If the external cleanliness is not met, the vendor or CCE will clean, re-inspect, and re-verify its cleanliness.

3.6.21 Packaging for Cleanliness

MAG-688 The TAM stored in or transported through an area that does not meet the cleanliness requirements of Class 100,000 or cleaner shall be packaged to protect the hardware against particulate and NVR contamination and to prevent inadvertent mechanical damage to the hardware.

3.6.22 Transportation Conditions

MAG-690 The TAM shall be transported using suitable containers that prevent against contamination, moisture, and inadvertent mechanical damage to the hardware.

3.6.23 ESD Labeling

MAG-692 All packaging and handling shall be in accordance with GPR-8730.6 Rev -, ELECTROSTATIC DISCHARGE (ESD) CONTROL.

4 VERIFICATION REQUIREMENTS

MAG-392 The contractor shall conduct a verification program that demonstrates the hardware design is qualified and meets all requirements contained in this document. The contractor shall provide a verification matrix defining the method of verification for each specific requirement of this document. Verification methods include inspection, analysis, test or a combination of these techniques.

4.1 INSPECTION

Verification by inspection includes visual inspection of the physical hardware, a physical measurement of a property of the hardware, or the documentation search demonstrating hardware of an identical design has demonstrated fulfillment of a requirement.

4.1.1 Visual Inspection

Visual inspection of the physical hardware by a customer appointed qualified inspector.

4.1.2 Physical Measurement

Physical measurement of hardware property (i.e. mass, dimensions, etc.) demonstrating the hardware meets specific requirement.

4.1.3 Documentation Search

MAG-400 Verification of requirements based on similarity shall include supporting rationale and documentation and shall be approved by the GSFC COTR.

4.2 ANALYSIS

Verification of performance or function through detailed analysis, using all applicable tools and techniques, is acceptable with GSFC COTR approval.

4.2.1 Factors of Safety

MAG-404 Structural analyses shall be performed to show positive margins of safety based on the factors of safety show in the table below.

Table 4-1 Factors of Safety

Type of Hardware	Design Factors of Safety	
	Yield	Ultimate
Tested Flight Structure - metallic	1.25	1.4
Tested Flight Structure - beryllium	1.4	1.6
Tested Flight Structure - composite(1)	N/A	1.5
Tested Flight Structure - pressurized glass(2)	N/A	3.0
Tested Flight Structure - unpressurized glass	N/A	3.0
Untested Flight Structure - unpressurized glass	N/A	5.0
Untested Flight Structure - metallic only	2.0	2.6

4.3 TEST

Verify by test represents a detailed test of performance and/or functionality throughout a properly configured test setup where all critical data taken during the test period is captured for review.

MAG-445 Performance parameter measurements shall be taken to establish a baseline that can be used to assure that there are no data trends established in successive tests that indicate a constant degradation of performance within specification limits that could result in unacceptable performance in flight.

4.4 TEST FACTORS

MAG-447 The following test factors and durations, shown in the table below, shall be used for prototype, protoflight, and flight hardware. The hardware definitions are included in the General Environmental Verification Standards (GEVS) for Flight Programs and Projects (GSFC-STD-7000).

Table 4-2 Test Factors and Durations

Test	Qualification	Protoflight	Acceptance
Structural Loads			
Level	1.25 X Limit Load	1.25 X Limit Load	Limit Load(2)
Duration			
Centrifuge	1 Minute	30 Seconds	30 Seconds
Sine Burst(1)	5 Cycles Full Level	5 Cycles Full Level	5 Cycles Full Level
Acoustic			
Level	Limit Level +3dB	Limit Level +3dB	Limit Level
Duration	2 Minutes	1 Minute	1 Minute
Random Vibration			
Level	Limit Level +3dB	Limit Level +3dB	Limit Level
Duration	2 Minutes/Axis	1 Minute/Axis	1 Minute/Axis
Sine Vibration			
Level	1.25 X Limit Level	1.25 X Limit Level	Limit Level
Sweep Rate(3)	2 Octaves/Minute/Axis	4 Octaves/Minute/Axis	4 Octaves/Minute/Axis
Shock			
Actual Device	2 Actuations	2 Actuations	1 Actuations

MAG-480 (1) Sine burst testing shall be done at a frequency sufficiently below primary resonance as to ensure rigid body motion.

MAG-481 (2) All composite structures must be tested to 1.25 x limit loads.

Pressurized glass structures shall be tested to 2.0 x limit loads.

MAG-482 (3) Unless otherwise specified these sine sweep rates shall apply.

4.5 TEST RESTRICTIONS

4.5.1 Failure During Tests

MAG-485 The test shall be stopped if equipment fails during testing in cases where this failure will result in damage to the equipment. Otherwise, the test shall be completed to obtain as much information as possible. No replacement, adjustment, maintenance, or repairs are authorized during testing. This requirement does not prevent the replacement or adjustment of equipment that has exceeded its design operating life during tests, provided that after such replacement, the equipment is tested as are necessary to assure its proper operation. A complete record of any exceptions taken to this requirement shall be included in the test report.

4.5.2 Modification of Hardware

MAG-487 Once the formal acceptance test has started, cleaning, adjustment, or modification of test hardware shall not be permitted.

4.5.3 Re-Test Requirements

MAG-489 If any event, including test failure, requires that a component be disassembled and reassembled, then all tests performed prior to the event shall be considered for repeat. If the unit has multiple copies of the same build, then all units shall be examined to determine if the problem is common. If all copies require disassembly for repair, then each shall receive the same test sequence.

4.6 REQUIRED VERIFICATION METHODS

The following measurements, tests, environments, and inspections are required for each TAM to provide assurance that the TAM meets specified performance, functional, environmental, and design requirements. Each test or demonstration is described below.

a. Weight and Envelope Measurements
b. Initial Alignment (if necessary), Performance and Functional Tests
c. Shock Test (if necessary)
d. Loads Test (Prototype/Protoflight only)
e. Sine Vibration
f. Random Vibration
g. Thermal Vacuum
h. Final Alignment (if necessary), Performance and Functional Tests

4.6.1 Weight and Envelope Measurement

MAG-501 Measurement of the weight and envelope of the TAM shall be made to show compliance with specified requirements and provide accurate data for the mass properties control program.

4.6.2 Performance Tests

MAG-503 The TAM shall be tested to demonstrate compliance with performance requirements, including alignment if necessary. Performance Tests are detailed functional tests conducted under conditions of varying internal and external parameters with emphasis on all possible modes of operation for the component. A Performance Test shall be conducted at the beginning and end of each acceptance test. Functional Tests are abbreviated Performance Tests done periodically during or following the component environmental testing in order to show that changes or degradation to the component have not resulted from environmental exposure, handling, transporting, or faulty installation.

4.6.3 Load Tests

MAG-505 Structural design loads per the levels in Table 4-2 shall be applied to prototype or protoflight hardware. There is no requirement to strength test flight hardware that has already been strength tested through a prototype or protoflight program (i.e., there is no "acceptance level" strength test requirement for flight hardware).

MAG-506 Structural Loads testing shall be verified by performing either a fixed frequency Sine Burst test, or a series of static loads pull tests.

MAG-507 No permanent deformation may occur as a result of the loads test, and all applicable alignment requirements shall be met following the test.

MAG-848 Components that require alignment shall have an alignment check following loads testing.

MAG-849 A performance test shall be conducted to verify that no damage occurred due to the loads test.

4.6.3.1 Sine Burst

A simple Sine Burst test following the random vibration test in each axis is a convenient method to conduct a structural loads test. This test applies a ramped sine input at a sufficiently low frequency such that the test item moves as a rigid body. An analysis is required to show that a base drive Sine Burst test will not cause over-test or under-test in some areas of the structure.

Test Duration: 5 cycles of full level amplitude.

4.6.3.2 Static Pull

Static pull tests are another method to perform loads testing and can be applied at flight interfaces in a static test facility. The loads can be applied either as component loads applied simultaneously, or the single resultant vector load can be applied to the test point. Strain gages are generally positioned around the test point to verify deflection predictions from the analytical model.

Test Duration: 30 seconds

4.6.4 Random Vibration

MAG-515 The TAM shall be subjected to a random vibration test along each axis to the appropriate levels shown in Section 3.6.2. The test item shall be mounted to the test fixture as it would be mounted to the spacecraft. A functional test shall be performed before the start of testing and after a test in each axis.

MAG-516 Prior to the test, a survey of the test fixture/exciter combination shall be performed to evaluate the fixture dynamics and the proposed choice of control accelerometers.

MAG-517 The Test Duration for the test shall be 1 minute per axis for Acceptance and Protoflight Tests and 2 minutes per axis for Prototype Tests.

4.6.5 Sine Vibration

MAG-519 The TAM shall be subjected to swept sine vibration testing to the appropriate levels in Section 3.6.2. The sweep rate shall be 4 octaves/minute for Acceptance and Protoflight Tests and 2 octaves/minute for Qualification Tests.

MAG-520 The Signature Sine sweep shall be conducted on each component before and after vibration testing in each axis. This test is a tool to verify no change in structural integrity from testing and to verify the primary resonant frequency meets requirements of Section 3.3.3.

4.6.6 Thermal Vacuum Test

MAG-522 Each component shall be cycled a total of eight (8) times at the component level. During these tests, chamber pressure shall be less than 1.33 X 10-3 Pa. (1 X 10-5 Torr).

4.6.6.1 Temperature Transitions

MAG-524 Transitions from cold to hot conditions increase contamination hazards because material that has accreted on the chamber walls may evaporate and deposit on the relatively cool test item. Transitions will be conducted at rates sufficiently slow to prevent that from occurring. Testing shall start with a hot soak and end with a hot soak to minimize this risk.

4.6.6.2 Hot/Cold Turn-On Demonstration

MAG-526 Components or subsystems shall be turned on twice after exposure to hot and cold survival temperatures. (see the profile of).

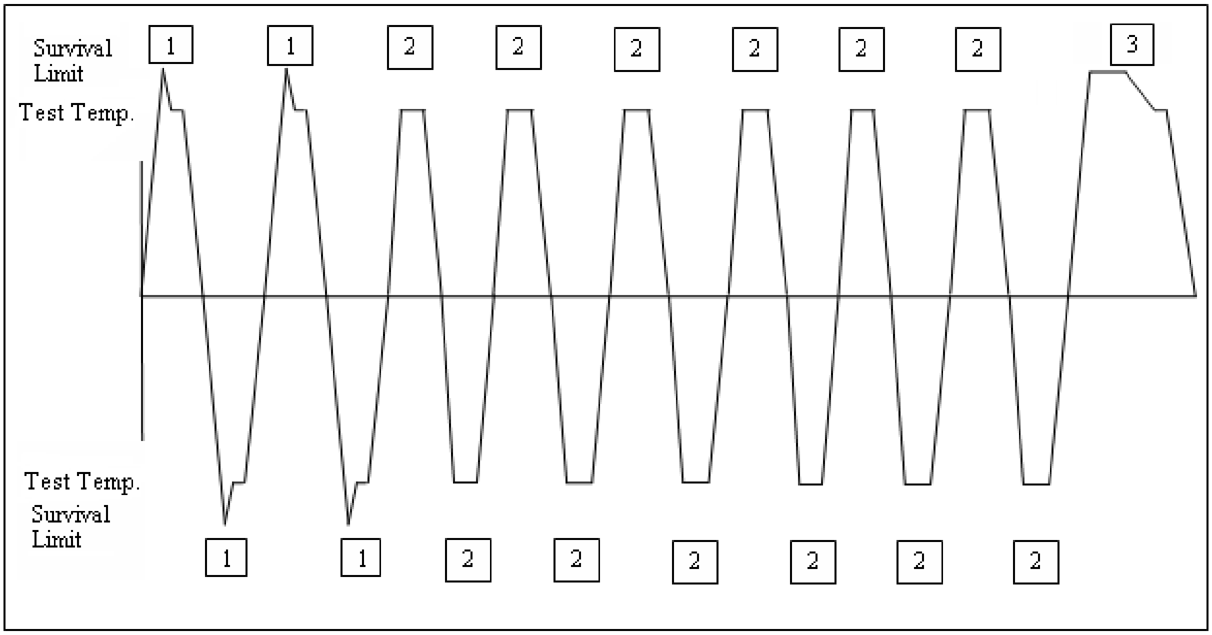
4.6.6.3 Thermal Vacuum Test Profile

Number of complete cycles:

Prototype Unit: 8 full cycles, start and end on hot cycle. Use Qualification Temperatures per Table 3-7 as the “test temperature” in Figure 4-1. Soak at test temperature 4 hours.

Protoflight Unit: 8 full cycles, start and end on hot cycle. Use Qualification Temperatures per Table 3-7 as the “test temperature” in Figure 4-1. Soak at test temperature 4 hours.

Flight / Copy / Spare Unit: 8 full cycles, start and end on hot cycle. Use Acceptance Temperatures per Table 3-7 as the “test temperature” in Figure 4-1. Soak at test temperature 4 hours.



1 = Achieve survival temp, stabilize 1 hour, return to test temperature, turn on, soak at test temperature 4 hours, run performance test.

2 = Soak at test temperature 4 hours, run performance test

3 = Bakeout phase

Figure 4-1 Thermal Vacuum Profile 8 Hot/Cold Cycles with Bakeout

4.6.6.4 Bakeout

MAG-537 The TAM shall be baked-out prior to delivery to GSFC (see Figure 4-1). The bake-out performance shall be measured using a temperature-controlled Quartz Crystal Microbalance (TQCM) at chamber pressures below 1.0E-5 torr. The bake-out shall be performed at the hardware's maximum hardware survival temperature, unpowered, for 48 hours followed by a 12 hour period, powered, at the maximum operational temperature as defined in Table 3-4. The TQCM shall be maintained at -20C throughout the test to measure total outgassing of volatile outgassed condensables without the influence of water vapor. The TQCM must have a representative view of the hardware, preferably a vent.

MAG-538 The following test data shall be collected and delivered to GSFC: Chamber configuration (ie. chamber size, use of shrouds, TQCM location, cold finger/scavenger plate locations (if used), and general test setup), TQCM readings (taken as a minimum every 0.5 hours), hardware temperature, chamber/shroud temperature, TQCM temperature, and pressure

MAG-539 If the Contractor's vacuum chamber uses a shroud to elevate and sustain an item's temperature for bake-out, background TQCM measurements shall be conducted before the bake-out with chamber in bake-out configuration in order to determine flight hardware contribution. Provision shall be made to measure effectiveness of pump system. The value of a chamber's exit conductance is generally much lower than the rating of its pump alone. This is necessary to relate TQCM deposition rates to source outgassing rates

MAG-540 If the Contractor uses a bake-out box, the chamber shall feature a shroud held at temperatures below the TQCM reading so as not to interfere with it, otherwise the bake-out box shall feature a coldplate near the bake-out box vent to collect contaminants that would otherwise interfere with the TQCM readings. In such cases, knowledge of the chamber pump effectiveness is not necessary.

4.6.6.5 Outgassing Certification Requirements

MAG-542 Each flight item shall meet an outgassing certification requirement to be verified during thermal vacuum bakeout or thermal vacuum testing. The outgassing certification requirement shall be measured with a TQCM. The contractor must meet an outgassing rate of 1.3 x 10-10 g/cm2/s using a temperature controlled quartz crystal microbalance (TQCM). The results of the test shall be submitted to the GPM Project for approval. The data set shall be recorded at least once every 30 minutes, for a minimum of 5 hours, during testing and shall contain, as a minimum, QCM data, temperature of hardware, QCM temperature, and chamber pressure. In addition, the chamber configuration and cold finger data shall be delivered with the results.

4.6.7 Polarity and Orientation Testing

All GNCS hardware shall be verified by test or inspection of the proper polarity and orientation for which these parameters affect performance.

APPENDIX A. ABBREVIATIONS AND ACRONYMS

Abbreviation/ Acronym	DEFINITION
AMS	Aerospace Material Specification
ANSI	American National Standards Institute
AO	Atomic Oxygen
atm	atmosphere
CLA	Coupled-Loads Analysis
C	Centigrade
CCB	Configuration Control Board
CCR	Configuration Change Request
CG	Center of Gravity
CM	Configuration Management
cm^2	Centimeters squared
CMO	Configuration Management Office
COTR	Contracting Officer Technical Representative
DA	Displacement Amplitude
dB	Decibel
dB/oct.	Decibel per octave
DC	Direct Current
ESD	Electrostatic Discharge
FOV	Field of View
g	grams
GEVS	General Environmental Verification Standards
GPM	Global Precipitation Measurement
GSFC	Goddard Space Flight Center
HDBK	Handbook
Hz	Hertz
kg	kilogram
km	kilometer
Lbs	pounds
mm	millimeter
MIL	Military
N/A	Not Applicable
NASA	National Aeronautics and Space Administration
Ohms/sq.	Ohms per square
SOW	Statement of Work
STD	Standard
TAM	Three-Axis Magnetometer
TID	Total Ionizing Dose
TIM	Technical Interchange Meeting
VDA	Vapor Deposit Aluminum
W/m^2	Watts per meter squared